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JNeurosci
THE JOURNAL OF NEUROSCIENCE

Research Articles: Behavioral/Cognitive

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Marieke van der Linden[1], Ruud M.W.J. Berkers[1], Richard G. M. Morris[2] and Guillén Fernández[1]

[1]*Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen Medical Centre, 6500 HB, Nijmegen, The Netherlands.*

[2]*Centre for Cognitive and Neural Systems, The University of Edinburgh, EH8 9JZ, Edinburgh, United Kingdom*

DOI: 10.1523/JNEUROSCI.3603-16.2017

Received: 23 November 2016

Revised: 12 August 2017

Accepted: 17 August 2017

Published: 4 September 2017

Author contributions: Conceptualization, M.vdL., R.B., R.M., and G.F.; Investigation, M.vdL.; Writing — Original Draft, M.vdL.; Writing — Review & Editing, M.vdL., R.B., R.M., and G.F.; Funding Acquisition, G.F. and R.M.

Conflict of Interest: The authors declare no competing financial interests.

The authors thank Hester Breman for programming the sdmcalculator plug-in for BrainVoyager. This research was funded by an ERC Advanced Grant (268800) to G.F. and R.M. R.B. is currently affiliated with the Max Planck Institute for Human Cognitive & Brain Sciences, Leipzig, Germany. M.v.d.L. is currently affiliated with Máxima Medisch Centrum, Veldhoven, The Netherlands.

Correspondence: Dr. Marieke van der Linden, Donders Institute for Brain Cognition and Behaviour, Centre for Cognitive Neuroimaging, PO Box 9101, NL-6500 HB Nijmegen, The Netherlands. E-mail: marieke.vanderlinden@gmail.com

Cite as: J. Neurosci ; 10.1523/JNEUROSCI.3603-16.2017

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Marieke van der Linden*[1]

Ruud M.W.J. Berkers[1]

Richard G. M. Morris[2]

Guillén Fernández[1]

[1.] Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen Medical Centre, 6500 HB, Nijmegen, The Netherlands. [2.] Centre for Cognitive and Neural Systems, The University of Edinburgh, EH8 9JZ, Edinburgh, United Kingdom

*Correspondence: Dr. Marieke van der Linden, Donders Institute for Brain Cognition and Behaviour, Centre for Cognitive Neuroimaging, PO Box 9101, NL-6500 HB Nijmegen, The Netherlands. E-mail: marieke.vanderlinden@gmail.com

Abbreviated title: AG promotes durable but less specific memories

Words abstract: 139/250

Words intro: 670/650

Words discussion: 1498/1500

Number of figures: 8

Number of tables: 2

Acknowledgements

The authors thank Hester Breman for programming the sdmcalculator plug-in for BrainVoyager. This research was funded by an ERC Advanced Grant (268800) to G.F. and R.M. R.B. is currently affiliated with the Max Planck Institute for Human Cognitive & Brain Sciences, Leipzig, Germany. M.v.d.L. is currently affiliated with Máxima Medisch Centrum, Veldhoven, The Netherlands.

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Abstract

After consolidation, information belonging to a mental schema is better remembered, but such memory can be less specific when it comes to details. A neuronal mechanism in line with this behavioral pattern could result from a dynamic interaction that entails mediation by a specific cortical network with associated hippocampal disengagement. We now report that in male and female adult human subjects, encoding and later consolidation of a series of objects embedded in a semantic schema was associated with a build-up of activity in the angular gyrus (AG) that predicted memory 24h later. In parallel, the posterior hippocampus became less involved as schema objects were successively encoded. Hippocampal disengagement was related to an increase in falsely remembering objects that were not presented at encoding. During both encoding and retrieval, the AG and lateral occipital complex (LOC) became functionally connected and this interaction was beneficial for successful retrieval. Thus, a network including the AG and LOC enhances the overnight retention of schema-related memories, and their simultaneous detachment from the hippocampus reduces the specificity of the memory.

Significance statement

This study provides the first empirical evidence on how the hippocampus and the neocortex interact dynamically when acquiring and then effectively retaining durable knowledge that is associated to pre-existing knowledge, but they do so at the cost of memory specificity. This interaction is a fundamental mnemonic operation that has been largely overlooked in memory research so far.

In time, most of the details of our experiences are forgotten. Some information is, however, retained for a longer period of time and thought to be stored in neocortical networks that are separate from the hippocampus (Scoville and Milner, 1957; Squire, 1986; Bontempi et al., 1999). This selectivity of memory retention is the basis of the standard model of system-level consolidation (Alvarez and Squire, 1994; Frankland and Bontempi, 2005). After consolidation, the medial prefrontal cortex (mPFC) and mid-line cortical regions have been observed to be activated during memory retrieval in rodents (Bontempi et al., 1999; Frankland et al., 2004; Maviel et al., 2004; Takehara-Nishiuchi et al., 2006; Takehara-Nishiuchi and McNaughton, 2008; Goshen et al., 2011) and humans (Takashima et al., 2006; Gais et al., 2007; Takashima et al., 2009; Bonnici et al., 2012).

Schemas provide a 'fast-track' into successful consolidation. Schemas are frameworks of acquired knowledge that are implemented in the brain as networks of interconnected neocortical representations (Wang and Morris, 2010). Schemas facilitate the assimilation of related new information, leading to better retention (Bransford and Johnson, 1972; Tse et al., 2007; van Kesteren et al., 2010b). The mPFC is more involved in processing memories congruent with a schema compared to schema-incongruent memories (van Kesteren et al., 2010b; Tse et al., 2011; van Kesteren et al., 2013b; van Kesteren et al., 2014; Brod et al., 2015). Initial evidence suggests that the parietal cortex also participates in applying a schema to an experimental task (Hanson et al., 2007; Sweegers et al., 2014; van Buuren et al., 2014).

This study investigates the possibility that the angular gyrus (AG) plays a key role in binding sensory content into a schema. Within the ventral parietal cortex, the angular gyrus (AG) is optimally located at the junction of visual, spatial, somatosensory, and auditory processing streams. These sensory-motor attributes all converge in the AG, where the perceptual details are believed to be abstracted (Fernandino et al., 2015) and bound together by semantic and conceptual associations (Binder et al., 2009b). After consolidation, the AG recombines schema components into a single memory representation (Wagner et al., 2015).

We sought to elucidate the roles of the MTL, mPFC, and AG in the encoding and consolidation of new information, followed by the later retrieval of recent (within-session) and remote (24 hr. earlier) schema-associated memories. During encoding, a series of four object photographs were presented in sequence (Figs. 1 & 2). In the schema condition these objects were all related to a real-world semantic schema (e.g. horse, spurs, boots, and a cowboy's hat). If the AG is involved in processing schema-related objects, successive presentation of these objects will modulate activity in the AG in a different way than a series of semantically unrelated objects. At the same time, the build-up of a schema could lead to disengagement of the hippocampus during encoding. An additional condition was included where the last object of the set was incongruent with the schema (e.g. a Christmas tree instead of the cowboy's hat). We expected the AG to respond differently to the final object based on its incongruence with the preceding object set. Finally, we also considered the implications of schemas with respect to subsequent retrieval. Shimamura (2011) suggested that the AG links "episodic features with long-term memory networks", an idea that leads to the prediction that such networks (schemas) will be recruited as the schema is built up. This dynamic process could in turn influence the encoding and/or consolidation of schema-related information, and that the AG should differentiate between subsequent retrieval of objects that were embedded in a schema during encoding compared to objects that were not.

The neocortical regions that likely support lasting memory representations include brain areas involved in the original processing of the stimulus at encoding (Tulving and Thomson, 1973; Nyberg et al., 2000; Danker and Anderson, 2010), and in the case of visually presented objects, these include ventral visual areas such as the lateral occipital complex (LOC). To test our prediction that the AG would be functionally connected to visual representation areas during encoding and item recognition, and that successful linking to these object representations would be beneficial to memory retention, we included a functional localizer scan.

Materials and Methods

Participants

In total, 31 participants participated in the experiment. For 7 participants, the data were excluded from the final analyses for the following reasons: Two participants did not complete the study; one participant moved 12 mm during scanning; one participant fell asleep during encoding on the second day; three participants displayed memory performance that did not exceed chance level. The presented results stem from a dataset with 24 right-handed participants (2 males, 22 females - mean age: 23.5 years, range 18-30 years). All participants were neurologically healthy and were paid for their participation (10 euro per hr., with an additional 2 euro per every 10% that they scored above 50%, i.e. chance level). For two out of 24 participants, the data sets were incomplete because of scanner malfunction during one of the encoding sessions. For these incomplete data sets, the data were adjusted in further analyses (i.e. the objects they did not see during encoding were removed from the item recognition test, maximum of 20% of the trials).

Stimuli

Stimuli consisted of color photographs of objects. These photographs were taken from the Hemera Object Database and Google image search. Objects were shown on a white background and were made to fit exactly in a box of 300x300 pixels while keeping their aspect ratios intact.

In our experiment, a schema was defined as a group of objects that are all related to each other through a semantic theme. More specific, a schema consisted of four pictures of objects (a quartet) from the same theme (see Figure 1a for an example of a “knight” schema). In total we used 100 themes, consisting of places, characters, seasons, sports, events, holidays, professions, rooms, countries etc. The schemas were created by selecting sets of 4 objects that ostensibly fitted within a theme, based on a separate preparatory study (N=20). In this, participants were presented with a theme, written on a screen, and they were instructed to type in the names of at least 10 objects that they associated with this theme. The nine objects that were mentioned most frequently were used

to form two quartets per schema and one related new object (schema-based lure). Schema-strength of an object was identified as the proportion of participants that mentioned an object within a given theme. When creating the quartets, the schema-strength of the objects was taken into account such that this was divided equally over positions in the quartets (on average 27.5% for each of the four positions). A second type of quartet (incongruent) was constructed by shuffling the Schema quartets' final objects around so that this object did not fit with the other three objects in the quartet anymore (Fig. 1a). We also constructed 100 No schema quartets in which there was no a priori association between the objects (see also Fig. 1a for an example). The schema consistency of the schemas - and the absence of schema for the No schema quartets - was confirmed in a second preparatory study (N=20). A different group of participants was asked to press a button during serial presentation of the objects in the quartets as soon as the schema was known to them. For the No schema quartets, there were no reports of schemas by the participants, whereas for the Schema quartets the average number of participants that correctly reported the schema was 90% (15% SD).

Image acquisition

During encoding and retrieval whole-brain images (T2*-weighted multi-echo planar imaging, 39 slices, 2 mm thick with 0.5 mm gap, repetition time = 2190 ms, in plane resolution = 2.5 × 2.5 mm^2, four echo times: TE1 = 9.4 ms, TE2 = 21.9 ms, TE3 = 34 ms, TE4= 47ms, flip angle = 90°, field of view = 21.2 cm) were acquired on a 3T whole body MR scanner (MAGNETOM Skyra by Siemens Medical Systems, Erlangen, Germany). Fat saturation was turned off. During the functional localizer scan, we acquired whole-brain images (echo planar imaging, 45 slices, 2 mm thick with 0.5 mm gap, repetition time = 2390 ms, in plane resolution = 2.5 × 2.5 mm^2, TE = 30 ms, flip angle = 90°, field of view = 21.2 cm). In addition, a high resolution structural T1-weighted 3D magnetization prepared rapid acquisition (MPRAGE) gradient echo sequence image was obtained after the functional scan (192 slices, voxel size = 1×1×1 mm).

Experimental Design and Statistical Analysis

Design and procedure

Participants were scanned on two consecutive days (see Figure 2a). On the first day, they encoded (for 53 min) the first set of objects (called the "remote" condition by virtue of its distance from retrieval the next day). Before they started with this first encoding session, they were scanned using a functional object localizer. After 24 hr. (sleep duration was on average 7.9 hr. with a standard deviation of 45 min), they returned to the lab for the second encoding session ("recent" condition, 53 min). After the second encoding session, they had a short break outside the scanner and then returned inside the scanner for the item recognition memory task probing memory for both remote and recent items (58 min).

Functional localizer

An independent functional localizer was included to allow us to investigate at a later time point whether PPI connectivity maps from memory areas overlapped with visual representation areas that preferentially respond to objects. The participants were told what the purpose of the localizer scan was and that they need not memorize the pictures they were shown. We used a block design using 32 photographs of common objects (unrelated to the schemas in the main experiment) and 32 scrambled pictures from a standard functional localizer task to localize the lateral occipital complex (LOC, (Malach et al., 1995). Images had grey backgrounds and measured 500 x 500 pixels. Images were randomly assigned to blocks of 17 images (each image was displayed for 400 ms and followed by a blank screen of 600 ms). Each block lasted 16.4 seconds. Within each block 16 images were unique and one image was repeated. The participants were instructed to detect this repetition by pressing a button with the index finger of the right hand. Each block was followed by a blank screen interval of 10 seconds. Each image was presented twice to the subject, but within different blocks. Four blocks of objects and four blocks of scrambled objects were presented. The localizer run lasted 3.5 mins.

Encoding

During each of two memory encoding sessions (called 'remote' and 'recent' in chronological order of presentation), 150 quartets were serially presented to the participants, one object after the other, see Figure 1a and Figure 2b. Quartets belonged to three schema conditions: First, the Schema condition, in which all objects in the quartet belong to one theme. Second, the Incongruent condition, in which the final item of the quartet was incongruent with the theme provided by the first three items. Third, the No schema condition, where there was no obvious association (schema) between the objects. The participants were instructed to remember all objects and quartets. They were also told that during the final memory test they would be presented with very similar lures so that they should try to remember as many details as possible. Simultaneously, they were asked to indicate for each object whether it would fit inside a shoebox. They responded "yes" and "no" with their index and middle finger of their right hand. Participants were told that memorizing the objects and quartets had priority over the "shoebox task". A black fixation cross was visible on screen throughout the encoding session and this fixation cross changed to red to signal the start of a new quartet. The red fixation cross was presented for 500 ms. The objects were presented for 1500 ms and the inter-stimulus interval was 3.5 s on average. All inter-stimulus intervals were jittered between 1.5 and 5.5 s. During each encoding session they were presented with 600 objects, so across the two encoding sessions participants memorized 300 quartets containing 1200 objects. We installed a few safe-guards to minimize memory to specific items (that arise from some objects being more memorable than others): First, the quartets were counterbalanced between subjects over remote and recent encoding sessions. Second, targets and lures were counterbalanced over subjects. Third, the quartet's final objects were semi-counterbalanced over schema conditions, as the objects in the fourth position of each quartet could not be swapped between Schema and No Schema quartets. As such, final objects were counterbalanced over Schema and Incongruent conditions across subjects, and a second counterbalancing was performed in terms of the assignment of objects to the Incongruent and No Schema Conditions.

Retrieval

Retrieval was tested by an item recognition memory task. The experiment started with 3 practice trials with objects that were new and not seen before (to familiarize the participant with the timing of the events and the task). During the item recognition task, the participants were presented sequentially with photographs of objects in a pseudorandom order. The quartets' final items were presented as old targets (Figure 1b). A perceptually similar lure was included for each target (Fig 1b). Half of the targets were presented before the lure, and half after the lure. Moreover, the spacing in time between a target and its lure was maximized. In addition, fifty objects that were related to a schema, but that were not presented during encoding, served as new Schema objects during retrieval (Fig 1b). There were another 50 objects that were new and were not related to the presented schemas, the new No schema objects. This resulted in a total of 700 objects that were presented to the participants (see Fig 2c for an overview of all conditions).

After the presentation of a fixation cross (500ms), each object was presented for 1500 ms, Figure 2b. Subjects rated their memory for the objects using a confidence scale, ranging from 1 (very surely old) to 6 (very surely new). Half of the participants responded "old" with their index, middle, and ring finger of their right hand and responded "new" with their index, middle, and ring finger of the left hand and this was reversed in the other half of the participants. After a jittered interval (average = 3.5 s, range: 1.5 – 4.5 s), during which the confidence levels were displayed on screen, the next object was presented.

After the retrieval session the participants filled in a short questionnaire asking them about strategies used during encoding (90% reported using the schemas during encoding) and retrieval (17% reported using the schemas during retrieval) and the amount of sleep on the previous night (on average 8 hr.).

Behavioral data analyses

For each subject the proportion of hits ("old" responses to old objects), misses ("new" response to old objects), correct rejections ("new" response to new objects and similar lures), false alarms ("old" response to new objects and similar lures), and "no responses" were calculated per condition as well as the confidence levels and response times for each of these variables. Trials were included at all levels of confidence, because there was above chance memory performance at all confidence levels. To account for response bias, we subtracted the proportion of false alarms made when presented with the New No schema objects, from respectively the proportions of Schema, No schema, and Incongruent hits (to targets) and false alarms (to lures). Proportion of hits minus false alarms and response times were tested in two (separate) multivariate analyses of variance (MANOVAs) with 2 factors: Schema condition (with 3 levels: Schema, Incongruent, and No schema) and Study-test delay (with 2 levels: Remote and Recent). Additional differences between conditions were tested using paired-samples and one-sample *t*-tests. All reported *p*-values are two-tailed. Alpha was set to 0.05.

MRI data analyses

The multi-echo fMRI data were processed using in-house software written in Matlab 7.5 (The Mathworks, Inc., Natick, MA, USA), which used the first 29 scans of the session (during which the experiment had not yet commenced) to calculate the optimal weighting of echo images for each voxel (i.e. by using a weighted measure of the contrast- to-noise ratio for each echo/scan). Motion correction was performed with reference to the first echo and the realignment parameters were applied to the other echoes by using iterative rigid body realignment. Next, calculations of optimal echo-weight for each voxel were used to combine multi-echo fMRI data into single images. The combined images were further processed using BrainVoyager QX (by Brain Innovation, Maastricht, The Netherlands). Images were slice-time corrected (using sinc interpolation). Co-registration of functional and 3D structural measurements was computed by relating T2*-weighted images and the T1-weighted MPRAGE measurement, which yields a 4D functional data set. Structural 3D and

functional 4D data sets were transformed into Talairach space (Talairach and Tournoux, 1988) and spatially smoothed with a Gaussian kernel (FWHM = 8 mm).

The expected BOLD signal change was modeled using a gamma function (tau of 2.5 s and a delta of 1.5) and convolved with each presented object (Boynton et al., 1996). Regressors were time-locked to the onset and duration of the presentation of the objects. Data were corrected for serial correlation using the AR2 method and a percent signal change transformation was performed before statistical analysis. Statistical analyses were performed using the general linear model. For the encoding sessions we modeled the three conditions (Schema, Incongruent, and No schema) separately and subsequently remembered or forgotten separately. This means that all objects in a quartet were categorized as to whether the final object was remembered or forgotten (e.g. Condition1_Object1_Remembered, Condition1_Object2_Remembered, Condition1_Object3_Remembered, Condition1_Object4_Remembered). In the encoding sessions, the contrasts included only the final objects from the quartets. For the contrast between remembered and forgotten items, the items that were forgotten were collapsed across schema conditions, this ensured more trials in the forgotten conditions and we presume the same process for forgetting in all conditions (e.g. Schema remembered > Schema forgotten + No Schema forgotten + Incongruent forgotten).

We also constructed a parametric model in which the four objects within a block were given parametric weights (-1.5, -0.5, 0.5, and 1.5) and, per condition, the blocks were also divided depending on whether the final objects were subsequently remembered or forgotten. For the retrieval session we modeled the first 3 trials (not uniquely part of any condition: “warm-up” trials), hits, misses, false alarms and correct rejections separately for Schema, Incongruent, and No schema remote and recent objects, and to new No schema and new Schema objects, in total 29 regressors. Random-effects group analyses were performed using the analyses of variance (ANOVA) to test for interactions. The first analysis consisted of a random effects ANOVA with 3 factors: Schema

Condition (Schema, No schema, Incongruent), Study-test delay (Recent, Remote), and Memory (Hits, Misses).

In addition, in all models, six derivatives of the realignment parameters were included as well as regressors for spikes related to motion (one regressor per spike). Furthermore, *t*-tests were used to test contrasts between different conditions. Results were thresholded at the voxel level at $p < 0.001$ and corrected using Monte Carlo cluster threshold correction completed over 1000 iterations. Small Volume Correction was applied to the ventro-medial prefrontal cortex using False Discovery Rate correction on the voxels that were included in an anatomical mask of Brodmann areas 32 and 24. Significantly activated clusters in mPFC and angular gyrus (AG) were selected for a more sensitive region of interest (ROI) analysis. For the ROI analyses the beta values were extracted from all voxels within the ROI and averaged over ROI, subject, and condition. The ROI time courses were standardized, so that beta-weights (regression coefficients) of predictors, as indices of effect size, reflect the BOLD response amplitude of one condition relative to the variability of the signal. Beta-weights were obtained for all voxels within these regions of interest, per subject and per condition. Differences between the subject-averaged beta-weights were investigated by paired *t*-tests with a threshold set at $p < 0.05$. All *t*-tests were two-tailed.

Finally, functional connectivity analyses (PPI) were conducted to determine the interactions between physiological data in terms of the psychological processes of the experiment (Friston et al., 1997). PPI methodology followed the steps first described in Friston et al. (1997) and was implemented using a BrainVoyager plugin (sdmcalculator v0.2). For the PPI analysis on the retrieval data, the seed-region we used was the AG region that was found in the Schema > No schema contrast during retrieval. The time course was extracted and averaged across all voxels from this area for each subject. As the psychological regressor, we used the contrast Schema remote hits (+1) and No schema remote hits (-1). For a second PPI analysis, using the left parietal ROI, we used the same methodology. As the seed, we used the areas found in the contrast Schema > No schema and extracted per subject the time course from all voxels. The psychological contrast was the same

contrast as used for the previous PPI. To test for a general effect of correct responses on connectivity to the lateral occipital complex (LOC) we also calculated a PPI for remote No schema hits (+1) versus recent No schema hits (-1). For the PPIs on the encoding data we used as a seed the AG region that was active in the remote (Schema > No schema) > recent (Schema > No schema) and the LOC region from the functional localizer that was active for Objects > Scrambled.

To investigate the behavioral relevance of the connectivity between the seed and target areas, we performed a correlation analysis at the group-level (using Pearson's *r*) on the extracted PPI beta-values from the ROI with the behavioral measures: remote Schema hits, remote schema effect (Schema minus No Schema), and remote Schema false alarms. We also calculated correlation with behavioral measures (hits minus the false alarms to new No schema objects) and the schema build-up in the angular gyrus. Schema build-up was measured by subtracting beta-values to object four minus object two (the moment at which a schema can first be detected). The difference between two correlations was tested using software from Lee and Preacher (2013), available online.

Results

Behavioral data

An important property of schema-based memories is that there is a behavioral benefit i.e. better memory retention for schema-related memories as compared to no-schema memories. Although this schema effect can be apparent immediately for associative memory, other studies have found that the difference between schema and non-schema-based item recognition is largest after a period of consolidation (van Kesteren et al., 2013a; Durrant et al., 2015). Our data are consistent with the latter pattern (Figure 3a). For all schema conditions (Schema, No Schema, Incongruent) we calculated recognition performance as hits minus false alarms (where false alarms pertain to the new No Schema objects). Participants performed well above chance in all three conditions on both study-test delays (all $t(23) > 4.9$, $p < 0.0001$). However, there was a significant study-test delay by

Schema condition interaction ($F(2,22) = 3.67$, $p = 0.04$, Wilk's $\Lambda = 0.75$). There was no difference between schema conditions for recently studied objects (Schema > No schema: t(23) = -0.93, p = 0.36; Schema > Incongruent: t(23) = -1.37, p = 0.18). However, for objects encoded the day before, participants had better memory for information embedded in a schema quartet than for either objects encoded in the No schema condition (t(23) = 2.18, p = 0.04) or Incongruent quartets ($t(23)=2.51$, $p = 0.02$). Memory did not decline over 24hr for Schema objects ($t(23) = 0.86$, $p = 0.4$). In contrast, for No schema (t(23) = 3.01, p = 0.006) and Incongruent objects ($t(23) = 3.44$, $p = 0.002$), memory was poorer for remote than for recent objects. Response times for hits also decreased as a result of Study-test delay (F(1,23) = 23.03, p < 0.001, Wilk's $\Lambda = 0.50$), but there was no difference between Schema conditions on this measure. Given this comparison between recent and remote memories, the schema-benefit that we found on remote memory scores reflected better retention for schema-based memories (Figure 3b).

To investigate whether schema-based memories are less specific and more 'gist-based' (Winocur et al., 2010), we included similar lures for each target during retrieval, as well as new objects. Lures consisted of very similar exemplars of the final object of each quartet that had been presented during encoding (Fig 1b). If memory for objects within a schema is less specific, more false alarms would occur to the similar lures compared to other novel objects. Indeed, across conditions there were more false alarms to the similar lures than to new objects. The key finding was that false alarm rates were highest to the lures of the Schema objects that were encoded just before (Recent condition: Schema > No schema: $t(23) = 2.02$, $p = 0.055$; Schema > Incongruent: $t(22) = 2.21$, $p = 0.038$; Figure 3c). However, this pattern of results could also be explained by guesses informed by prior knowledge (i.e. when not sure about seeing the cowboy's hat, a participant might be more likely to press "old" because he/she remembered seeing items from a cowboy schema and therefore saying "old" to the cowboy's hat increases the chance of a hit). Therefore, we also included objects in the item recognition test that were not seen during encoding, but were congruent with the schemas used during encoding. We observed that these new 'Schema-related objects' did not elicit

more false alarms than the new 'Schema-unrelated objects'. If anything, there was a trend toward the opposite result (No schema > Schema: $t(23) = 1.92$, $p = 0.067$), with the subjects showing more correct rejections to the new Schema-related objects than the new Schema-unrelated objects ($t(23) = 2.307$, $p = 0.03$; Figure 3d). This latter finding indicates that the schema is actually beneficial to the correct identification of new related objects as incorrect lures. To conclude, the supposition that the schema is used for informed guessing can be ruled out. To the contrary, objects that were embedded in a schema during encoding have less specific but more resilient memory traces.

To summarize, we have shown that shortly after encoding the memory for Schema objects was already less specific, leading to more false alarms to lures from recently seen Schema objects, and that this difference between false alarm rates disappeared after a delay of 24 hr. In addition, we found a behavioral benefit for Schema objects after overnight consolidation. Schema objects showed no decay in item recognition memory performance, whereas the No schema and Incongruent objects did display forgetting. We conclude that Schema memories were less specific immediately after encoding, but were retained better over 24hrs.

fMRI data

Encoding

The neural correlates of subsequent schema memory

The behavioral data demonstrated that after a short delay recognition was at ceiling. The difference in memory performance between schema conditions became apparent after 24 hr., and was reflected in better retention of schema embedded objects. Therefore, the analysis of subsequent memory effects here relates to the delay by schema interaction found in memory performance. To identify brain regions specifically involved in retention, t-test comparisons were performed comparing the subject-averaged 'beta-maps' from the schema contrasts between the remote and recent encoding sessions (using the contrast (remote Schema remembered > remote No schema remembered) > (recent Schema remembered > no Schema remembered)). We found that the

angular gyrus (AG) showed a Schema > No schema difference that was larger for remote than for recent encoding (Figure 4a, red overlay). For the separate contrast of Schema > Incongruent over time (remote versus recent encoding), we did not find any region at conventionally corrected thresholds (but an uncorrected voxel threshold of 0.005 did point to differential activation in the angular gyrus, hippocampus, superior frontal, and cingulate gyrus.

We plotted the event-related subject-averaged time course and the subject-average beta-weights from the AG region that displayed a larger schema effect with consolidation (Fig 4b and 4c). For all conditions, activation started at a comparable level, but then progressively differed as the schema unfolded. Activation built up monotonically for both the Schema and Incongruent quartets, but this effect was not seen for the No schema quartets. Importantly, activity dropped for the Incongruent condition when the final object no longer fitted the previously built-up schema. Since the AG-region was defined based on the Remote (Schema > No Schema) > Recent (Schema > No schema) contrast, we did not perform inferential statistics comparing the extracted signal across conditions.

To test whether this build-up of a schema is predictive of better performance at retention, we calculated the amount of activity in the schema that was build-up (from the first moment the schema can be inferred at object position 2, up to the final 4^{th} object of the quartet). This measure of schema build-up in the AG in individual participants during encoding correlated with 24 hr. retention measured as Schema hits minus false alarms (the latter pertaining to the New No Schema lures) of those same participants [$r = 0.43$, $p = 0.036$]. This correlation implies that the build-up of schema activity in the AG is beneficial for retaining object memories over 24 hr. This effect was specific to objects encoded in the first, i.e. 'remote encoding session'. In the recent encoding session, there was no schema-build up that was specific for the subsequently remembered objects and no positive correlation between a possible build-up (the difference in activity to object 4 minus object 2) with successful memory retrieval scores [$r = 0.04$, $p = 0.85$]. We also tested whether the activity decrease for the fourth object (response to the fourth object minus response to the third object) in the

Incongruent quartets would be indicative of memory performance (hits minus false alarms to New No Schema objects) as this object might stand out more, similar to an oddball, but we found no evidence for this [r = -0.8, p = 0.71].

Schema build-up across object sequences

An analytically interesting comparison can be made between the final objects of the Schema and Incongruent quartets that were remembered after 24 hrs. In both cases, these objects were preceded by three objects that belonged to a schema, with only the Incongruent fourth object being out of place. Importantly, this contrast was significant in the angular gyrus (bilaterally) and the right supramarginal gyrus (Fig 4a, green overlay). This means that whereas a host of regions was preferentially activated for a series of schematically congruent versus incongruent objects, only the angular gyrus and supramarginal gyrus were preferentially activated to the fourth object being congruent or incongruent with the preceding object. This finding points to the angular gyrus as the candidate area for holding the schema representation.

The previous analyses already demonstrated (indirectly) a parametric build-up of activity in the AG as successive objects were presented. This build-up is clearly schema-related, as demonstrated by the observed difference between the contrasts for Schema and No schema objects, and between Schema and Incongruent. That is, the initial three objects are modulating AG activity build-up for Schema quartets that contain the subsequently remembered object. Although we had no reason to expect a similar parametric build-up for the No schema condition, a general alteration of activity as a consequence of sequential visual input could not be ruled out. However, our data establish that the AG is not a candidate area for such a general effect, but there might be other regions that do show either a parametric build-up or even a parametric decline. Therefore, we also performed whole-brain analyses to identify regions where activity was modulated by a parametric regressor in either encoding session, for quartets that contained subsequently remembered objects. The parametric regressor represented the hypothesized build-up or decline of activation with each

successive presentation of an object in the quartet containing the remembered final object. We tested for activity that fitted the parametric regressor for the quartets containing the subsequently remembered final objects. An overview of all brain regions is presented in Table 1. In the remote encoding session, the remembered No schema quartets did not elicit reliable parametric variation in brain activity in any region, whereas the remembered Incongruent quartets showed a parametric increase in the left superior frontal gyrus and a decrease in the right angular gyrus. As expected, during the remote encoding session, activity for the schema quartets that contained the subsequently remembered objects was parametrically modulated in the angular gyrus, confirming the analyses presented above. A particularly interesting observation was a parametric decrease for the remembered Schema quartets in the hippocampus (Fig. 5a, blue overlay), suggestive of a disengagement of the hippocampus when encoding schema memories.

For the recent encoding session, we found no parametric modulation of activity in subsequently remembered Schema quartets. When taking remembered and forgotten schema quartets together, the left angular gyrus did show a parametric increase in activity (peak: x = -45, y = -64, z = 22 $t(23) = 3.99$, $p < 0.001$). This shows that for recently encoded objects the schema is being build-up in the angular gyrus as well, but that this build-up is apparently only beneficial for remembering these objects after a period of 24 hr. This is consistent with the build-up being associated with consolidation. We also found no parametric schema effect for subsequently remembered quartets (Schema parametric > No schema parametric). During remote encoding we found a parametric schema effect in areas that largely overlapped with the main effect of schema (see Fig 4a blue overlay and Table 2) including the AG.

Since the AG is being modulated by the build-up of a schema by presenting related objects, we suspected that the object representations in the ventral visual stream could be contributing to the schema build-up. A connectivity analysis (PPI) using the lateral occipital region from the localizer scan (objects > scrambled) as seed did indeed show that this region was connected to the AG during

encoding of schema objects, (see fig 4a orange overlay). This AG area overlaps almost completely with the AG regions showing a remote schema effect and schema build-up.

Interplay between AG and hippocampus during encoding of schema quartets

The parametric decrease that we observed in the hippocampus (Fig 5b) raises the intriguing possibility that the connection between the AG and hippocampus is inhibitory in nature and leads to the hippocampus becoming less involved in encoding memories when a schema is present. This fits with a model of accelerated systems-level consolidation for schema memories. Interestingly, the parametric value for the Schema decrease in the posterior hippocampus correlated negatively with the amount of schema build-up in AG (Fig 5c, r = -0.45, p = 0.027). This indicates that a greater schema build-up effect was paired with a stronger parametric decrease of activity in the hippocampus. This could mean that the AG, as it is becoming more involved in encoding Schema objects, starts signaling the hippocampus that its involvement is no longer necessary. To test this idea, we performed a PPI connectivity analysis with the same AG seed region, investigating increased connectivity as a function of the parametric build-up of a schema. This analysis revealed that the right posterior hippocampus is indeed functionally coupled to the AG during encoding and that the degree of connectivity is modulated in association with the parametric build-up of the schema during presentation of the quartets (Fig 5a, red overlay).

The differential expression of detailed versus gist-like memory representations may reflect differential activation in hippocampus and cortex. Specifically, if the hippocampus disengages, there may be a less detailed memory trace. We therefore examined the correlation between false alarms and AG-hippocampus PPI connectivity scores. Those participants with higher AG-hippocampus PPI connectivity did not show more false alarms to Schema lures (r = 0.07, p = ns), but they did show a higher rate of false alarms to new Schema objects (r = 0.48, p = 0.018). The higher number of false alarms to new objects from the same schema may indicate that when detailed memory of the

485 schema objects is lacking, because of less hippocampal involvement during encoding, the gist of the
486 schema prevails.
487
488 *Retrieval*
489 Interaction between schema condition and study-test delay in medial prefrontal cortex (mPFC) at
490 retrieval.
491 It was of interest to explore whether the neuronal schema effect during retrieval mirrors the schema
492 effect found during encoding and in the behavioral data, in the sense that they become apparent
493 only after consolidation. An interaction between Schema condition and Study-test delay was
494 observed in the medial prefrontal cortex during retrieval (mPFC, coordinates of the peak: x = -6, y =
495 39, z = 2, $F(1,23) = 26$, $p < 0.05$ Small Volume Corr.; Figure 6). To secure insight into the direction of
496 this interaction, we extracted beta-weights from the mPFC for remote and recent hits in each
497 condition. When comparing these subject-averaged beta-weights, we found that mPFC activity was
498 higher for Schema than No schema for remote hits (t=2.54, p = 0.011) and Schema activation was
499 also higher for remote than recent Schema hits (t=2.33, p = 0.020). However, Incongruent hits did
500 not differ from either Schema (remote: t = 1.39, p = 0.16) and No schema hits (remote: t = 1.09, p =
501 0.27). MPFC activity to Incongruent hits showed a trend towards increased activity over time
502 (Incongruent: remote > recent: t=1.87, p = 0.06). This interaction confirmed that the schema
503 differences in mPFC become apparent after a 24 h delay at the same time as the behavioral benefit
504 arises.
505
506 Schema effect in parietal cortex
507 To test whether there were brain areas that were more activated by Schema relative to No schema
508 during item recognition, we used a direct contrast between conditions (omitting the misses). We
509 found five areas that responded more to Schema than No schema, these were the right AG, left
510 parahippocampal gyrus, left precuneus (extending into the cuneus), the dorsal medial thalamic

nucleus, and left inferior parietal lobe (Figure 6). No areas were more active during retrieval of No schema or Incongruent objects than Schema objects. Since the AG showed behaviorally relevant schema activation during encoding, the AG and parietal areas were further inspected in an ROI analysis (Figure 7). Using a PPI analysis with remote Schema memories versus remote No schema memories (hits) we found connectivity with the AG to be higher for the remote Schema memories in several areas in the left hemisphere (Figure 8). Furthermore, we found increased connectivity between AG and LOC that correlated positively with correct recognition (proportion hits) of remote Schema objects (r = 0.42, p = 0.039). To rule out a general effect of retrieval success we also calculated the correlation between the PPI value in the AG and hits to No schema objects and there we found no correlation (r = -0.18, p = ns) and the difference between both correlations was significant (Z= 2.08, p = 0.038). These findings suggest that the AG is specifically involved in successful retrieval of schema objects.

Discussion

Schemas are believed to be beneficial for memory of conceptually related information (Bransford and Johnson, 1972) and thought to accelerate consolidation (Wang and Morris, 2010; van Kesteren et al., 2012; Ghosh and Gilboa, 2014). Here we found behavioral and neuroimaging evidence for accelerated consolidation for schema memories that could be linked to memory processes in the angular gyrus (AG), hippocampus, and medial prefrontal cortex (mPFC) during encoding, consolidation and retrieval.

First, objects embedded in a schema (that our subjects identified as successive stimuli were presented) were better remembered 24hr later compared to those that were either not embedded in a schema or incongruent with one. Second, during encoding, the AG showed an activity pattern that reflected the build-up of a schema. This build-up of activity was specific for schema memories that were retained for 24hr, with the amount of AG build-up predictive of memory retention. One interesting aspect of 'build-up' is that it parallels old data from Bransford (Bransford, 1979; Morris et

537 al., 1979), which suggests schemas are only effective as aids to memory if they are activated. This
538 was first shown in Bransford's famous story about 'washing clothes', a schema which everyone has
539 presumably obtained, but which in the story was obscured by the manner in which the passage of
540 prose was written. Once the theme was revealed, its effectiveness for supporting memory is
541 dramatic. Third, in parallel with the build-up in AG, we observed that the hippocampus decreased its
542 activity when a schema was presented. Disengagement of the hippocampus from encoding a schema
543 object fits with the notion that schemas are stored in the neocortex and accelerate systems-level
544 consolidation (Tse et al., 2007; Tse et al., 2008; van Kesteren et al., 2010a). It also provides a
545 potential explanation why schema memories were found to be less specific, or less detailed,
546 compared to memories that were not embedded in a schema.

547 There are subtle features of the behavioral data related to the specificity of memory. For
548 example, the behavioral schema effect (positive difference in memory scores between schema and
549 no-schema conditions) was not present immediately after encoding, but emerged after
550 consolidation. This fits with previous reports of a benefit for schema memories after a night of sleep
551 (Tse et al., 2007; van Kesteren et al., 2013a; Durrant et al., 2015). Comparing remote and recent
552 schema memories within participants enabled us to conclude that the schema effect reflects better
553 retention across time for schema objects, indicating that a schema makes memories more resilient
554 to forgetting. However, such a result could also be explained by using a schema for informed
555 guessing after a delay and we sought data that might help to distinguish between a consolidation
556 and guessing interpretation. Overall, for schema and non-schema conditions, participants made
557 more false alarms and less correct rejections to the lures that were similar to the targets relative to
558 new lures. This has also been reported in other studies (Gutchess and Schacter, 2012; Bowman and
559 Dennis, 2015). However, we also observed that our participants made more false alarms to similar
560 lures of targets that might potentially have been embedded in a schema during encoding relative to
561 lures from both non-schema conditions. This subtle detail indicates that schema memories can be
562 less detailed and possibly more gist-based. However, the critical comparison to rule out guessing

was whether the participants would falsely recognize new objects that were related to the schema but not seen during encoding; that is, they were first encountered during item recognition. It turns out they did *not* make more false alarms to these new schema lures compared to new no-schema lures. In fact, they made more correct rejections to the new schema lures. These findings together suggest that schemas are not used for guessing, but that objects related to a schema are encoded in a less specific manner, thereby giving rise to more false alarms directly after encoding.

Might the finding of less specificity for memories of schema objects be related to the reduced involvement of the hippocampus in memorizing objects from a schema? The hippocampus has circuitry well-suited for discriminating between studied items and similar lures, and does so through pattern-separation (Bakker et al., 2008; Yassa and Stark, 2011). In our study, we found that targets and similar lures from a schema were more difficult to dissociate. One possibility is that a schema could act, in part, as an inhibitor of hippocampal functioning, as proposed by the SLIMM framework (van Kesteren et al., 2012). In our experiment, the AG showed functional coupling with the posterior hippocampus. More schema-related activity in AG was associated with greater deactivation of the hippocampus. In addition, a larger influence of AG on hippocampus was related to more false alarms to new schema objects, indicative that the gist but not the details of the memory were preserved. Overall, the finding of less hippocampal involvement for schema memories fits with the findings from rodents (Tse et al., 2007; Tse et al., 2008) and humans (van Kesteren et al., 2010a; van Kesteren et al., 2014) and provides more evidence for accelerated consolidation of schema memories. In addition, it provides an explanation why schema memories seem less detailed and more gist-based (Lewis and Durrant, 2011).

What is the relative role of mPFC and AG? To date, the partial disengagement of the MTL memory system for schema-memories has been linked to the allocation of the neural correlates of schema memory to the medial prefrontal cortex (mPFC) – during both encoding (van Kesteren et al., 2010a; van Kesteren et al., 2012; van Kesteren et al., 2013b; van Kesteren et al., 2014) and retrieval (van Kesteren et al., 2010b; Brod et al., 2015). We found no evidence for involvement of the mPFC

589 during encoding of objects embedded in a schema, but the mPFC did show an interaction between
590 study-test delay and schema condition when monitored at the time of retrieval. This result confirms
591 extensive data pointing to the involvement of the mPFC in retrieving remote memories (Bontempi et
592 al., 1999; Frankland et al., 2004; Maviel et al., 2004; Takashima et al., 2006; Takehara-Nishiuchi et al.,
593 2006; Gais et al., 2007; Takehara-Nishiuchi and McNaughton, 2008; Takashima et al., 2009; Goshen
594 et al., 2011; Bonnici et al., 2012). In contrast, the retention of schema objects for 24hr was related
595 to a build-up of schema activity in the AG during encoding. The AG is high-up in the hierarchy of
596 convergence for unimodal and supramodal representations (Fernandino et al., 2015), which fits with
597 the content of a schema. In addition, the AG is involved in processing thematic relationships
598 (Kalenine et al., 2009), closely resembling the kind of schemas used in our experiment. This also fits
599 with the notion that the AG is a 'binding zone' that is believed to combine representations in a
600 conceptual manner (Binder et al., 2009a; Binder and Desai, 2011; Shimamura, 2011; Price et al.,
601 2015). This binding function of the AG has recently been linked directly to recombining visual
602 representations into schemas (Wagner et al., 2015), in accordance with our findings.
603 Connectivity analyses using PPI revealed that object representations in LOC seemed to co-
604 activate along with the related schema in AG. Typically, response patterns in LOC elicited by pictures
605 of objects show categorical clustering (Eger et al., 2008). This clustering is remarkably consistent
606 across species (Kriegeskorte et al., 2008) and reflects categorical as well as shape similarity (Bracci
607 and Op de Beeck, 2016). It is likely that the AG receives 'bottom-up' information when object
608 representations are activated that show conceptual clustering. The AG then binds these related
609 representations in a schema during encoding. During retrieval, the AG responded more to those
610 objects that were embedded in a schema during encoding compared to non-schema objects. This
611 likely reflects that the schema was also active during retrieval. Such retrieval-associated AG
612 activation of a schema (consisting of related and connected object representations) leads to the
613 expectation that the AG would similarly be connected to ventral visual representation areas such as
614 LOC during item recognition. The successful linking of the schema to these object representations

would be beneficial to memory scores, as was observed. In addition, connectivity from AG to visual representation area such as the LOC, overlapping with those found in our object localizer, was higher for remote schema memories than for remote No schema memories. This finding corroborates a recent study in which it was also shown that the interplay between AG and ventral visual areas was important for memory success (Kuhl and Chun, 2014). Thus, during retrieval, schema information is used to reactivate object representations in LOC and to match the target to the previously seen object representations.

To conclude, this study provides behavioral and neuronal evidence to support the idea that schemas give rise to improved memory consolidation. The mPFC is involved in the retrieval of memories dependent on schemas. However, at least for the type of task described here, the schema information itself appears to be stored in the AG. Schema activation in AG at encoding determines whether an object is successfully remembered after 24hr. The AG binds together schema-related object representations during encoding and uses this information again during retrieval. The simultaneous disengagement of the hippocampus from schema memory formation is further evidence for accelerated schema-associated consolidation and provides a potential explanation of why schema memories are less detailed.

Author contributions

Conceptualization, M.vdL., R.B., R.M., and G.F.; Investigation, M.vdL.; Writing – Original Draft, M.vdL.; Writing – Review & Editing, M.vdL., R.B., R.M., and G.F.; Funding Acquisition, G.F. and R.M.

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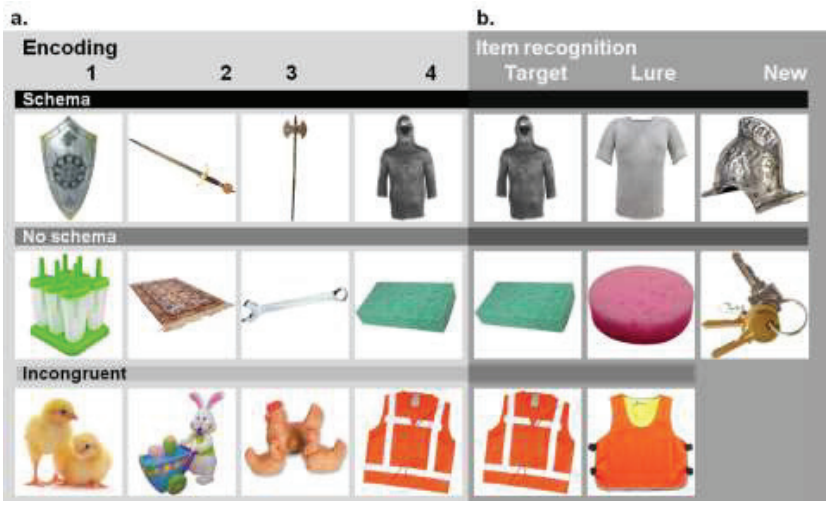
779 **Figures and legend**

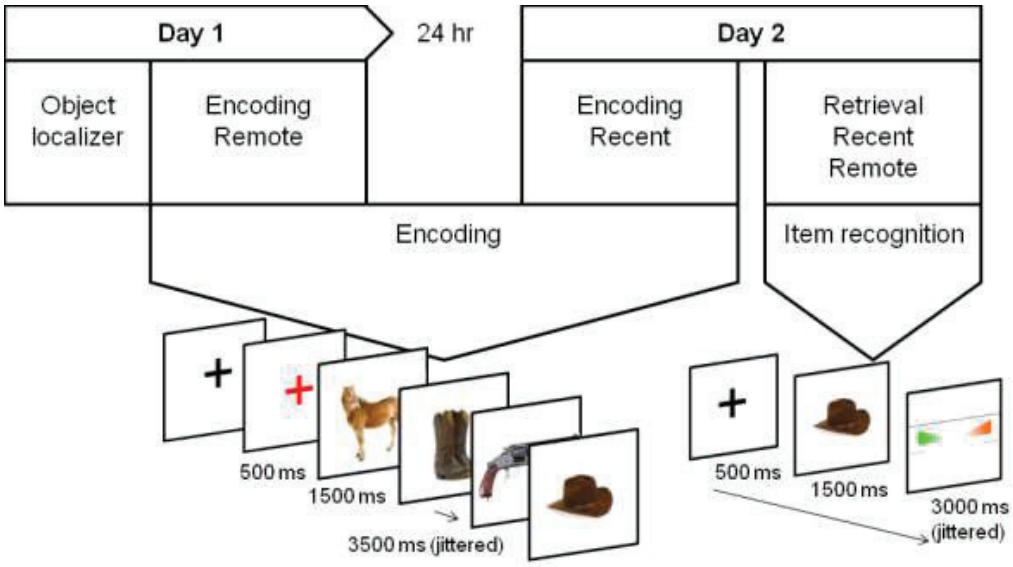
780 **Figure 1**

781 

782 **Fig 1. Stimuli. a.** During both encoding sessions, participants were presented with quartets
783 belonging to the Schema, No schema, and Incongruent conditions. A quartet consisted of four
784 objects that were presented serially. The first quartet (row 1) is an example of the "knight" schema.
785 Next, in the No schema condition (row 2), four objects that have no pre-existing association were
786 presented. For the Incongruent condition (row 3), the first three objects from the "Easter" schema
787 were followed by an incongruent final object (e.g. a high-visibility vest). **b.** During item recognition,
788 the participants were presented with the quartets' final objects (column 1). The quartet's final object
789 was presented once exactly as seen before (Target) and once as a very similar exemplar of the same
790 object (Lure; column 2). In addition (column 3), there were objects that were new and belonged to
791 the schemas that were presented (new Schema-related) or new but unrelated objects (new Schema-
792 unrelated).

793

794 **Figure 2.**



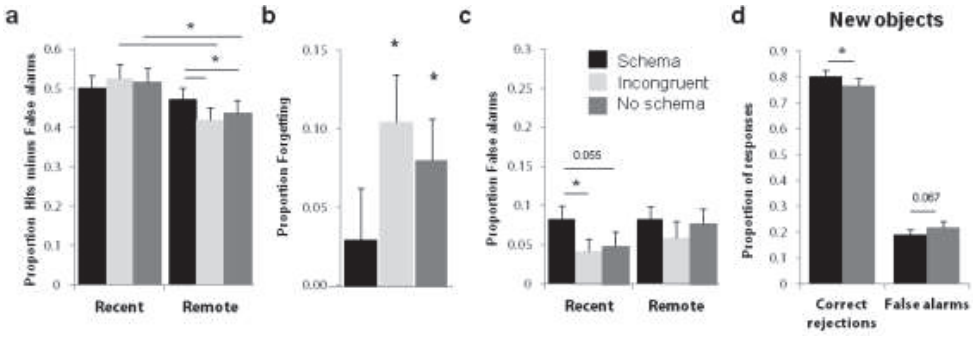
795

Item recognition conditions	New	Remote		Recent	
Schema	New	Target	Lure	Target	Lure
No schema	New	Target	Lure	Target	Lure
Incongruent		Target	Lure	Target	Lure

796 **Fig 2. Design. a.** Participants were scanned on two consecutive days. On the first day, they encoded
797 the first set of objects (remote condition). After 24 hr. they returned to the lab to encode the second
798 set of objects (recent condition). The second encoding session was followed by the item recognition
799 task after a short break. **b.** During encoding four objects were presented serially (for 1500 ms each).
800 Participants were instructed to memorize the objects and quartets and to indicate for each object
801 whether it fitted in a shoebox ("yes" or "no"). A black fixation cross was visible on screen throughout
802 the experiment and this fixation-cross changed to red to signal the start of a new quartet. The inter-
803 stimulus interval was 3.5 s on average. All inter-stimulus intervals were jittered between 1.5 and 5.5
804 s. During item recognition the participants were presented with pictures of objects (1500 ms). They
805 rated their memory for the objects using a 6-level confidence scale, ranging from 1 (very surely old)
806 to 6 (very surely new). After a jittered interval (average = 3.5 s, range: 1.5 – 4.5 s), during which the

807 confidence levels were displayed on screen, the next object was presented. **c**. Objects were
808 presented during item recognition across 14 conditions, with 700 objects distributed equally over
809 Schema condition (Schema, No schema, and Incongruent), Study-test delay (New, Remote, and
810 Recent), and Type of object (Target or Lure), resulting in 50 objects per bin.
811
812
813

814 **Figure 3.**



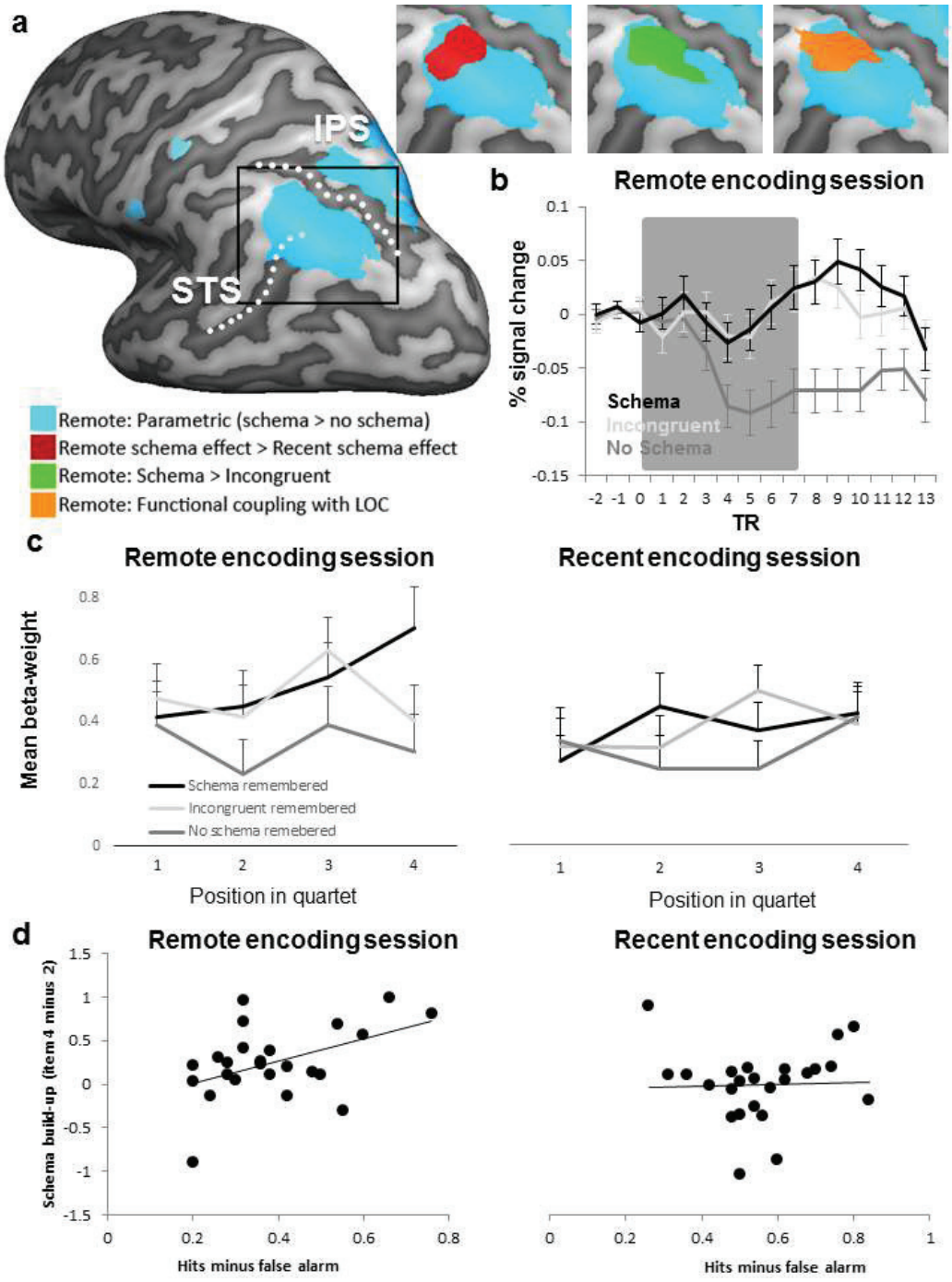
815

816 **Fig 3. Behavioral data. a.** Proportion of hits (hits minus false alarms to the new No schema condition)
817 are presented for recent and remote conditions for Schema, Incongruent and No Schema conditions.
818 **b.** Proportion of forgetting (recent minus remote hits) is presented for the three schema conditions.
819 **c.** Proportion of false alarms for all schema conditions (false alarms minus the proportion of false
820 alarms to the new No schema condition) are presented for recent and remote conditions. **d.**
821 Proportion of correct rejections and false alarms to the new No schema and new Schema objects are
822 presented. For all plots: black color represents the Schema condition, dark gray: Incongruent, and
823 light gray: No schema. Error bars represent the standard error of the mean (S.E.M.). * denotes a
824 significant *p*-value of < 0.05.

825

826

827 **Figure 4.**



828

829 **Figure 4. Schema effects in the AG during encoding. a.** Inflated hemisphere (left hemisphere, dark

830 gray areas are sulci) with overlays of four contrasts that all converge in the angular gyrus. In green,

areas that were more active in the remote encoding session to Schema than to Incongruent remembered final objects. In orange, areas that showed functional coupling with the LOC during encoding of subsequently remembered Schema objects. In red areas that showed a larger schema effect in the remote encoding session as compared to the recent encoding session ((remote Schema remembered > remote No schema remembered) > (recent Schema remembered > no Schema remembered)). In blue, areas that showed a parametric schema effect, i.e. a build up of activation with each object presentation (parametrically modulated activity during schema quartets > parametrically modulated activity during No schema quartets). The dotted lines present the superior temporal sulcus (STS) and intraparietal sulcus (IPS) and are depicted for anatomical reference. All maps were corrected at a cluster-level of $p < 0.05$ (voxel-level threshold was $p < 0.001$). **b.** The subject-averaged event-related time course from the AG region defined by the contrast: remote (Schema > No schema) > recent (Schema > No schema) and is presented by the red blob in Fig. 4a. We plotted the percent signal change at each TR (TR was 2190ms) for the three schema conditions (black: Schema, light gray: Incongruent, dark gray: No schema). The gray area indicates the time of the presentation of the quartet, the first object is presented at TR= 0 and the offset of the final object of the quartet is on average (with jittered intervals) at TR= 7. Error bars are S.E.M. **c.** For each encoding session, we plotted the subject-averaged beta-weight for each of the four objects in the quartet from the same ROI as used in Fig. 4b. In black for schema quartets, in light gray incongruent quartets and in dark gray No schema quartets. **d.** The correlation between the build-up of a schema (beta-weight to object 4 minus beta-weight to object 2) and the proportion of hits minus false alarms is plotted for both encoding sessions (from the same ROI as used in Fig. 4b). Remote encoding session is the session that was 24 hr. prior to retrieval. Recent encoding session was the session immediately preceding retrieval.

Figure 5

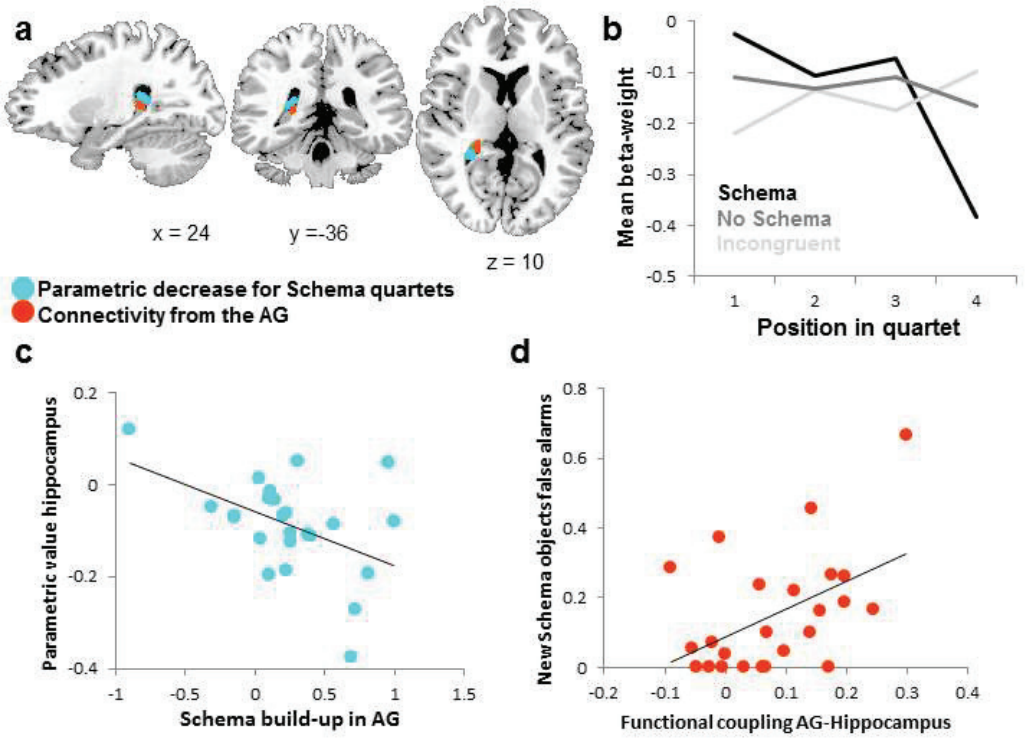


Figure 5. Hippocampal deactivation during encoding of Schema quartets. a. The blue overlay shows the posterior hippocampus area in which activity decreased parametrically for Schema quartets in the remote encoding session. Since the map shown is depicting a group-averaged, normalized, spatially smoothed overlay, voxels extend into the ventricle (6% overlap with the anatomical mask of the hippocampus). However, the peak voxel of the activation (x = 23, y = -37, z =13, parametric decrease t(23) = 4.398197, p < 0.001) falls within the posterior hippocampus. In red (98% overlap with the anatomical mask of the hippocampus) the result from the PPI connectivity analysis with the AG as a seed region showing that the posterior hippocampus is modulated by the parametric increase of schema-related activity in the AG. Both maps are thresholded at a cluster-level corrected $p < 0.05$. **b.** The subject-averaged beta-weights from the hippocampal ROI showing the parametric decrease (represented by the blue blob in Fig. 5a) for each of the four objects in the quartet as a function of schema condition. In black Schema quartets, in light gray Incongruent quartets and in

dark gray No schema quartets. **c.** Subject-averaged beta-values representing the parametric scores of the hippocampal ROI that showed a parametric decrease in activity (represented by the red blob in Fig. 5a) correlated with the amount of schema build-up in the AG. **d.** The PPI values from the connectivity analysis from the AG to the hippocampus correlate with the amount of false alarms participants made to the new Schema objects.

Figure 6

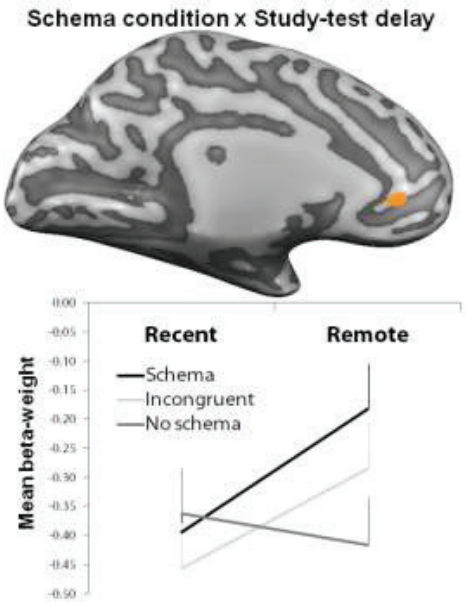
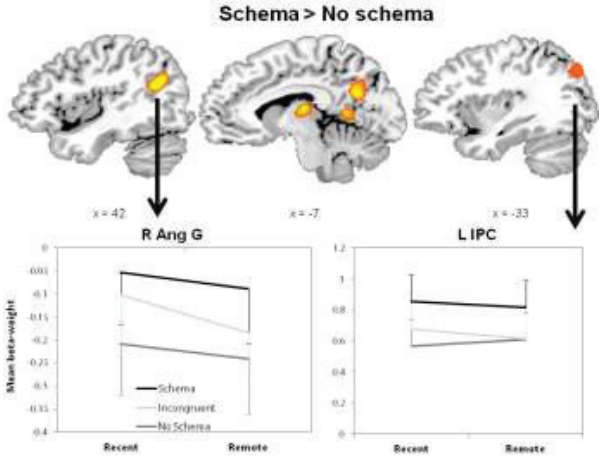


Fig. 6. Study-test delay by schema condition interaction during retrieval. We found a Study-test delay by Schema condition interaction in the right medial prefrontal cortex (mPFC, coordinates of the peak: x = -6, y = 39, z = 2, $F(1,23) = 26$, $p = 0.00004$, SVC *corr.* < 0.05) during retrieval. The mPFC result is presented on an inflated right hemisphere; dark gray colors represent the sulci. Plotted below are subject-averaged beta-weights extracted from all voxels within this mPFC region for Schema (black), No schema (dark gray), and Incongruent (light gray) remote and recent hits to provide information on the direction of the interaction and are shown here for this purpose (error bars reflect standard error of the mean).

885 **Figure 7**



886

887 **Fig. 7. Areas active during Schema retrieval.** The contrast between Schema and No schema objects
888 (collapsed over time) was displayed as an overlay on three sagittal slices. The graphs below present
889 the beta-weights from both ventral parietal areas (R Ang G, right angular gyrus and LIPC, left
890 intraparietal cortex). Error bars represent the standard error of the mean.

Figure 8

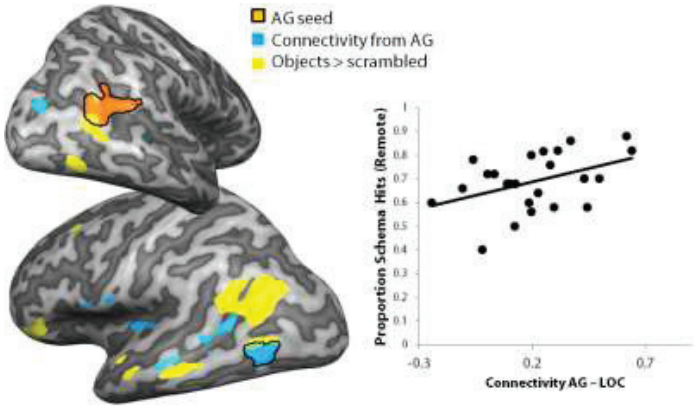


Fig 8. Angular gyrus connectivity during schema retrieval. Connectivity from the angular gyrus (AG) seed region (in orange) was explored with a PPI analysis for remote Schema objects compared to remote No schema objects (overlay in blue). These results are overlaid on two inflated hemispheres and combined with the overlay (in yellow) from the functional localizer contrasting objects with scrambled objects. The right graph represents the correlations between memory performance (proportion of hits in the remote condition) and PPI connectivity scores for Schema objects as indicator of the strength of the psychophysiological interaction (PPI).

Tables

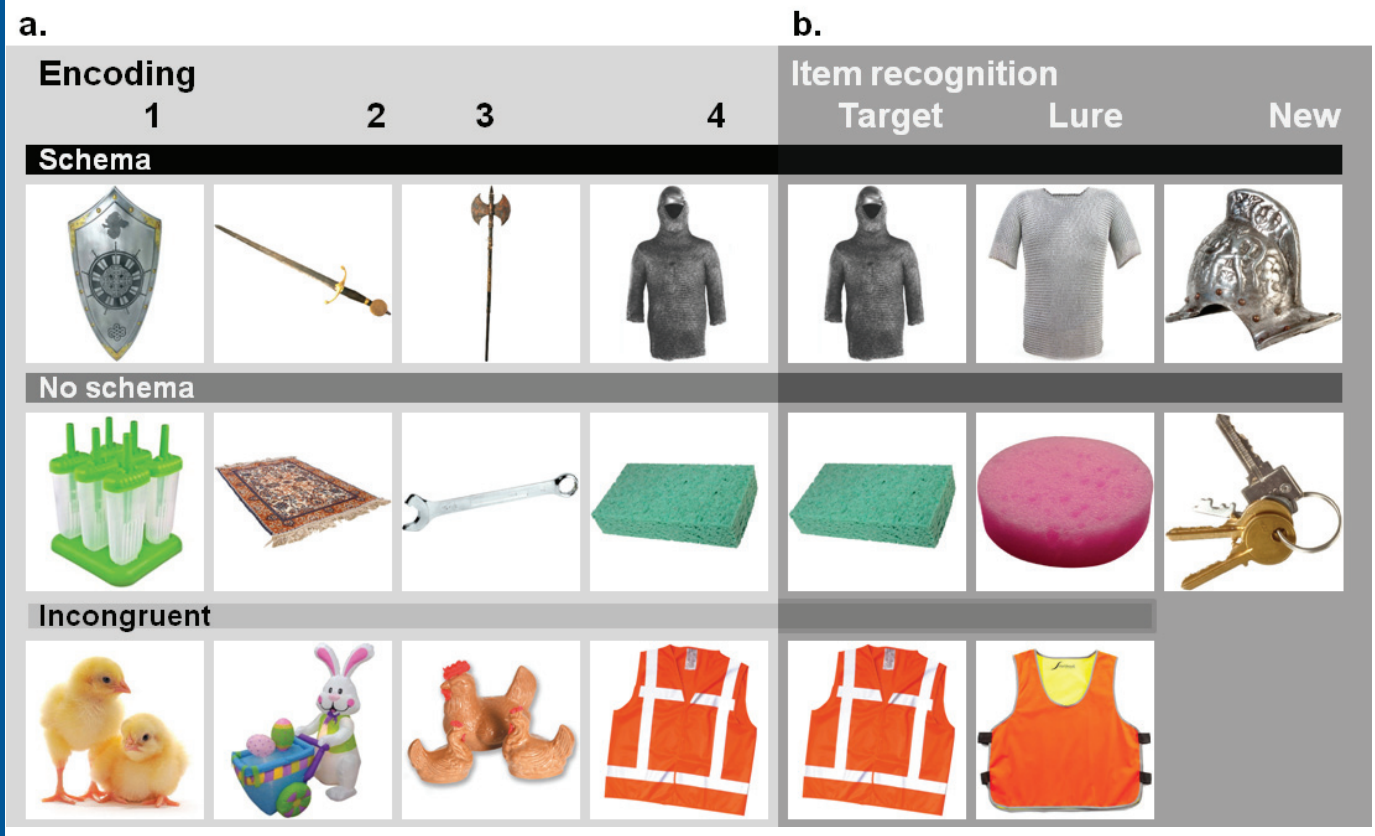
Area	x	y	z	t
Parametric increase				
R Middle Frontal G	30	17	31	5.40
Thalamus	12	-10	4	4.79
Parahippocampal G	-6	-61	4	5.47
L Inferior Frontal G	-30	32	19	5.56
L Angular G	-30	-67	37	5.91
L Superior Temporal G	-36	-25	10	4.72
Parametric decrease				
R posterior hippocampus	27	-40	10	-5.18

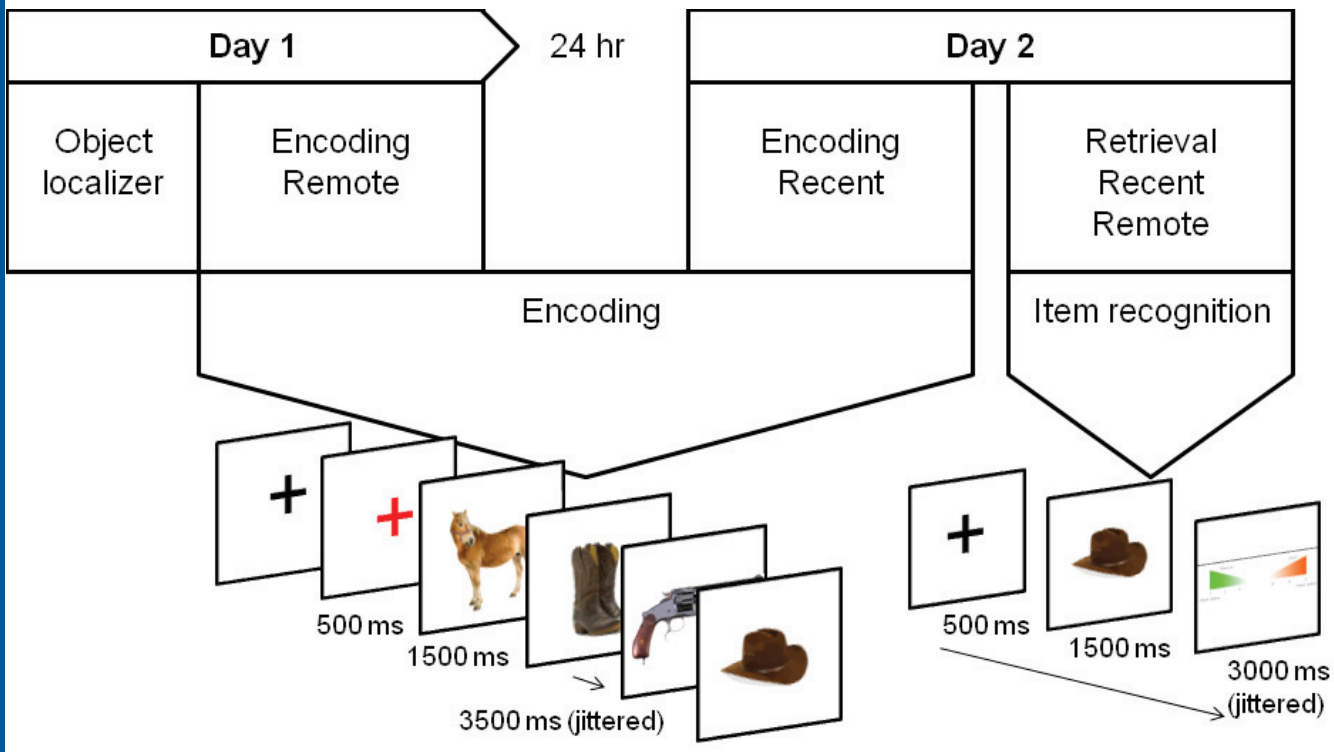
Table 1. Schema build-up. Areas modulated by the parametric regressor for schema build-up in the remote encoding session for quartets with a subsequently remembered final object. Coordinates are Talairach coordinates of the peak voxel. For all *t*-values (df = 23) *p* was < 0.0001.

Area	x	y	z	t
R Superior Temporal G	57	-1	4	4.51
Bilateral Parietal and Cuneus	9	-82	25	6.63
R Precentral G	33	-16	43	4.35
R Superior Frontal G	27	59	19	4.50
Precuneus	15	-46	40	5.46
L Inferior Occipital G	-6	-61	4	4.52
L Middle Frontal G	-30	53	10	5.98

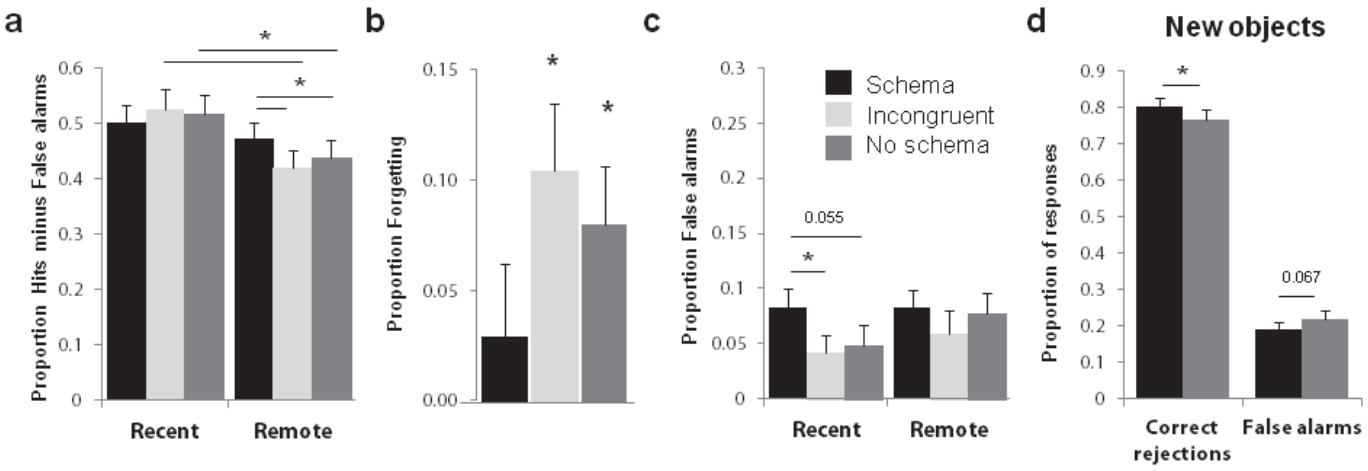
L Precentral G	-51	-22	40	5.03
L Postcentral G	-57	-22	22	5.07

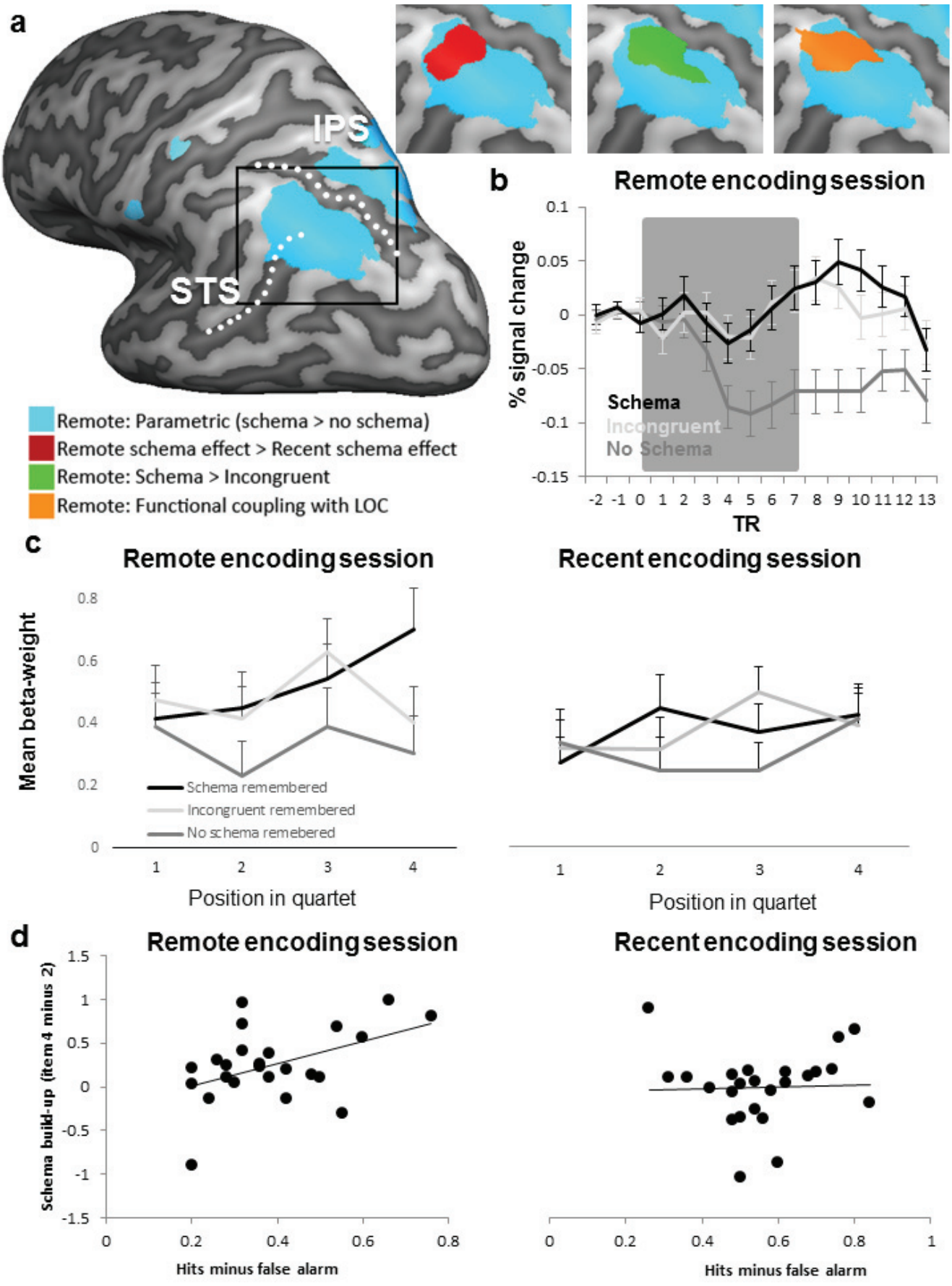
Table 2. Parametric schema effect. Areas that show a larger parametric build-up for Schema versus No schema quartets in the remote encoding session. Coordinates are Talairach coordinates of the peak voxel. For all *t*-values (df = 23) *p* was < 0.001.

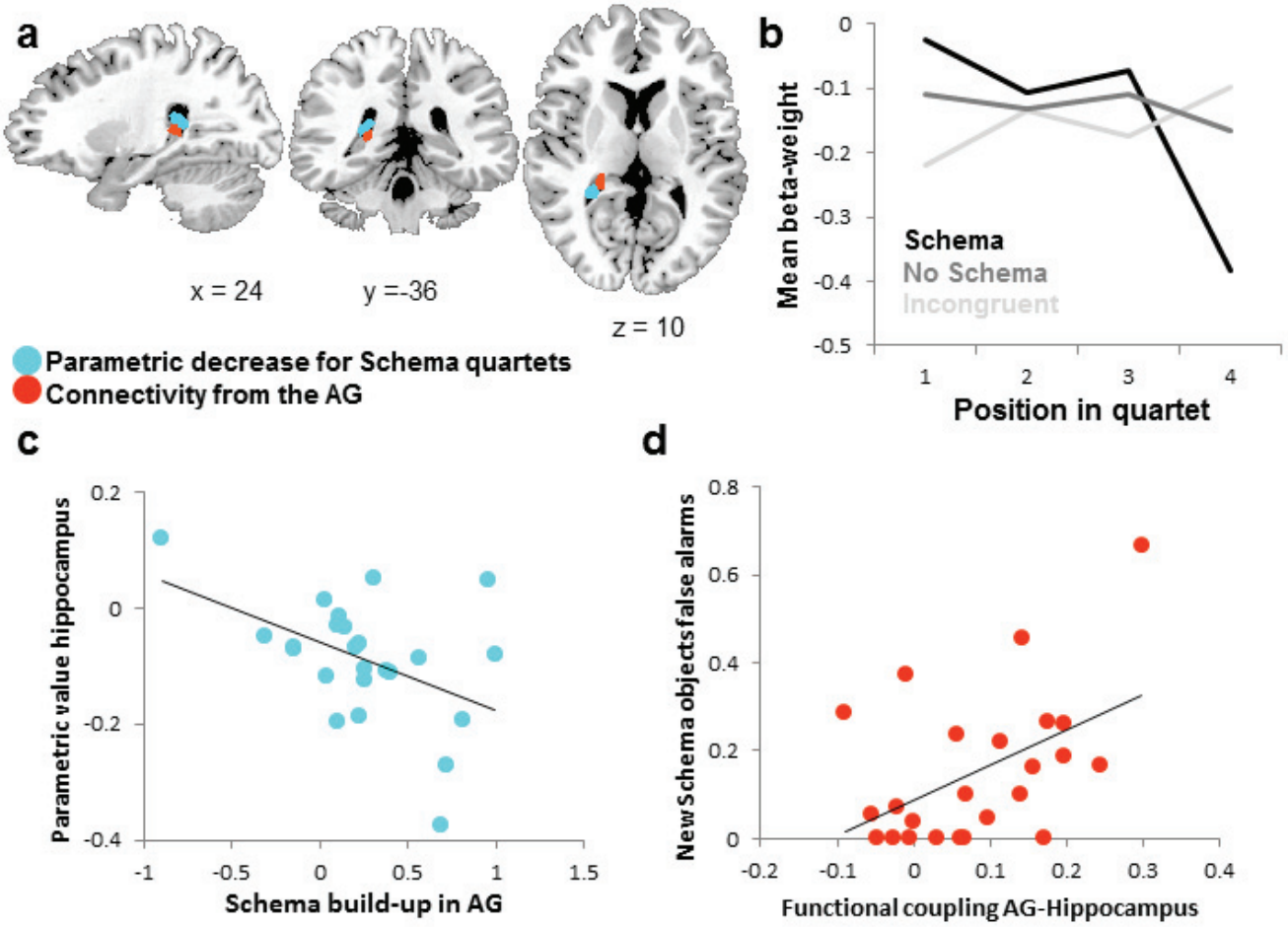


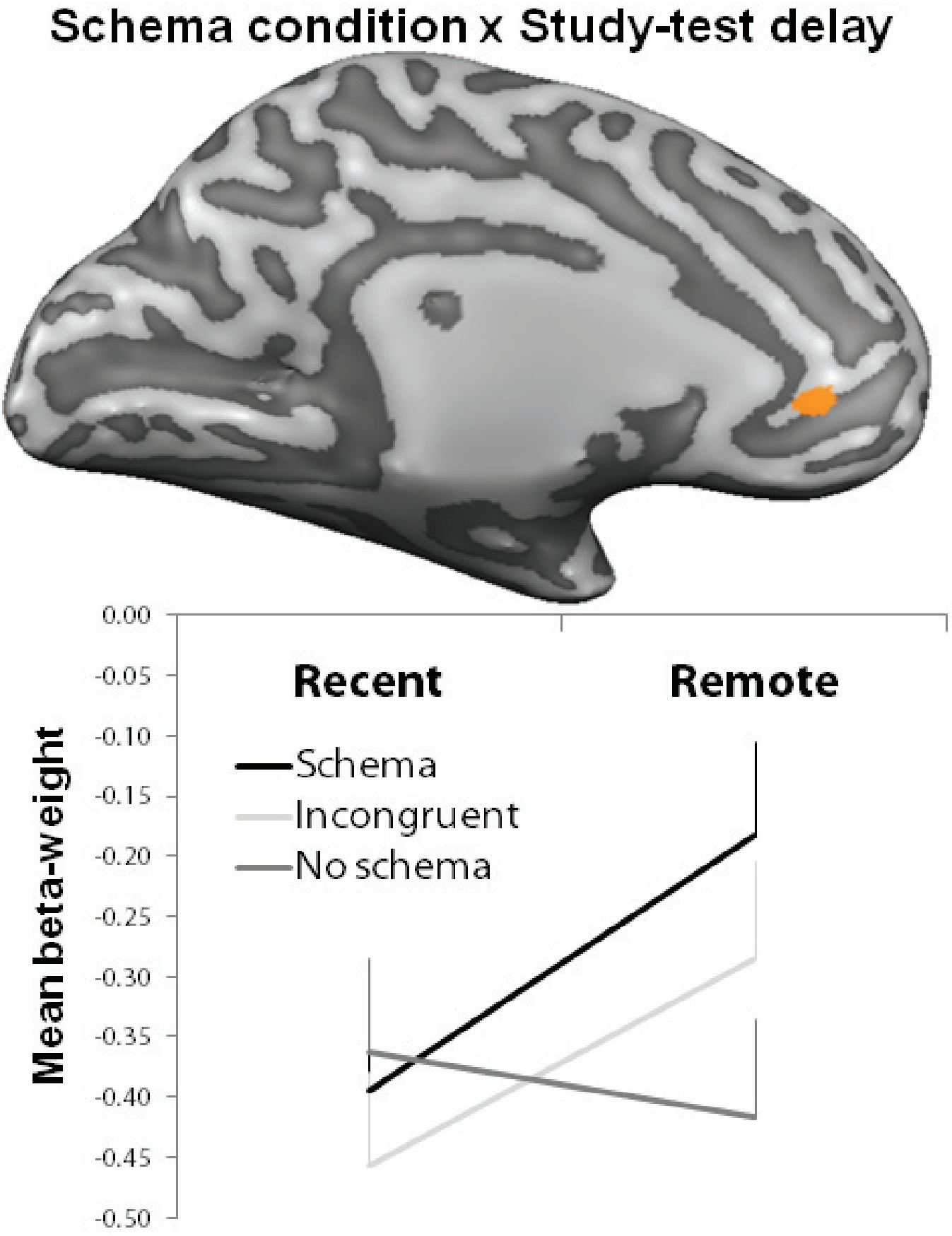


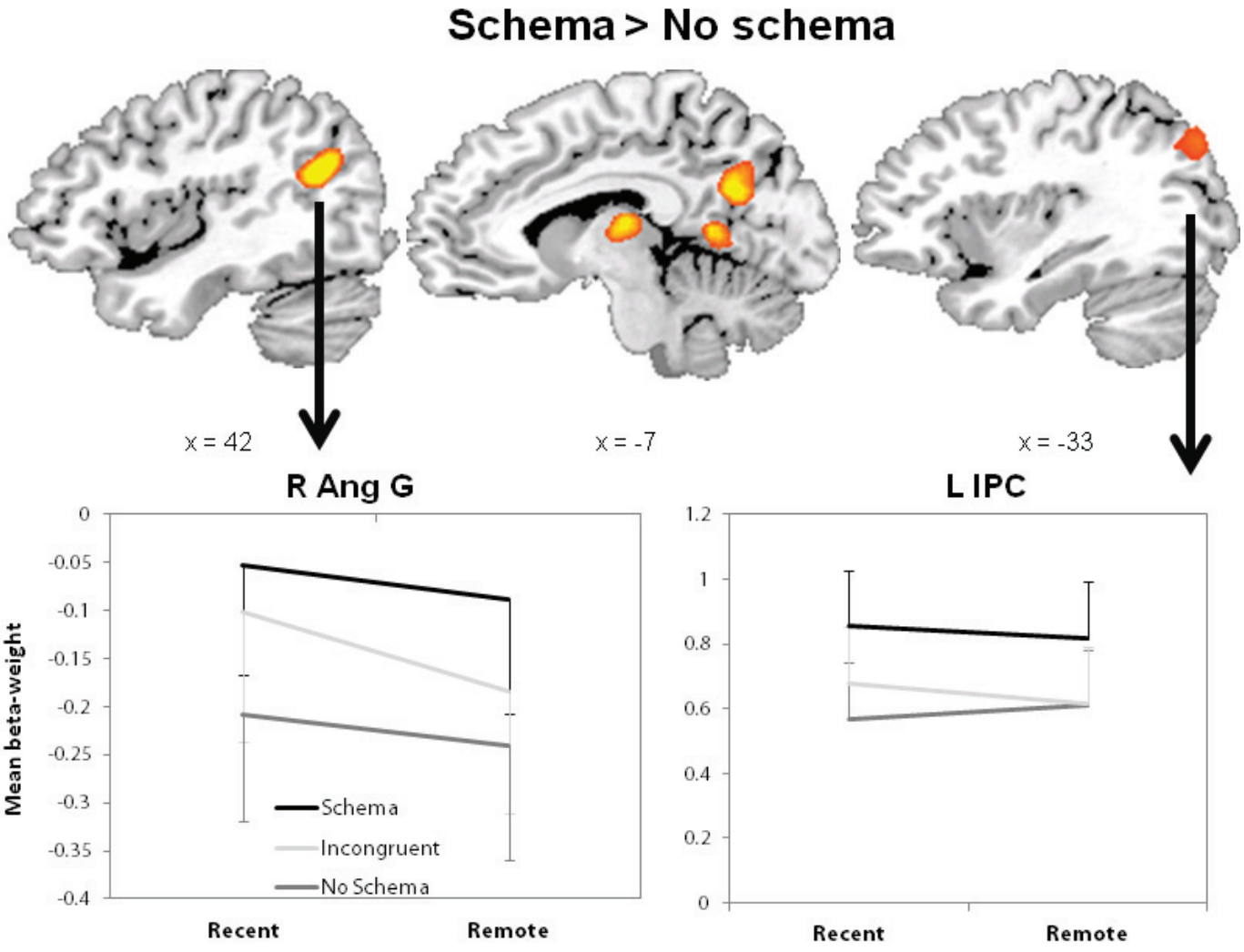
Item recognition conditions	New	Remote		Recent	
Schema	New	Target	Lure	Target	Lure
No schema	New	Target	Lure	Target	Lure
Incongruent		Target	Lure	Target	Lure

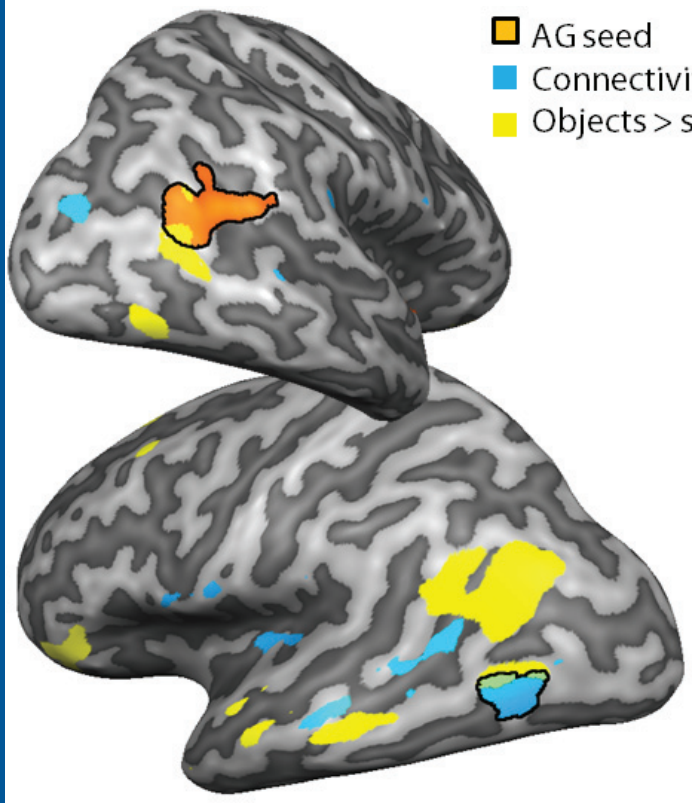












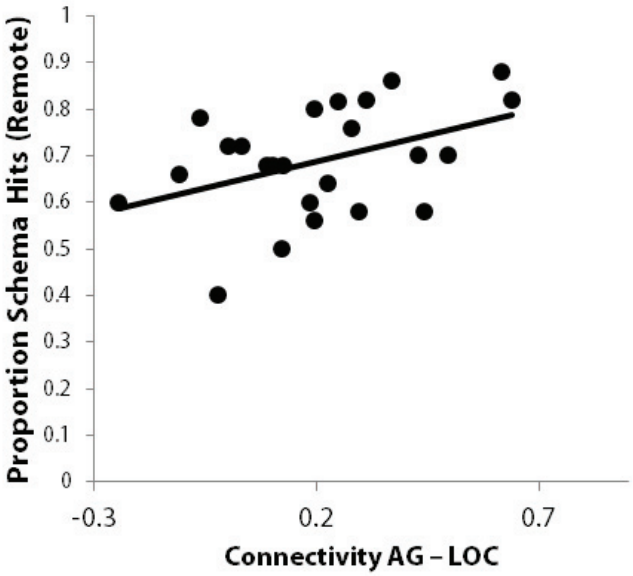


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Table 2. Parametric schema effect. Areas that show a larger parametric build-up for Schema versus No schema quartets in the remote encoding session. Coordinates are Talairach coordinates of the peak voxel. For all *t*-values (df = 23) *p* was < 0.001.